

Ultrasonic Measurement of Aircraft Strut Hydraulic Fluid Level

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ABSTRACT

An ultrasonic method is presented for non-intrusively measuring hydraulic fluid level in aircraft struts in the field quickly and easily without modifying the strut or aircraft. The technique interrogates the strut with ultrasonic waves generated and received by a removable ultrasonic transducer hand-held on the outside of the strut in a fashion that in the presence or absence of hydraulic fluid inside the strut. This technique was successfully demonstrated on an A-6 aircraft strut on the carriage at the Aircraft Landing Dynamics Research Facility at NASA Langley Research Center. Conventional practice upon detection of strut problem symptoms is to remove aircraft from service for extensive maintenance to determine fluid level. No practical technique like the method presented herein for locating strut hydraulic fluid level is currently known to be used.

INTRODUCTION

A typical aircraft landing gear strut configured with a metering pipe in the middle and nitrogen gas above the hydraulic fluid is represented in figure 1. Strut fluid level typically must be verified in aircraft service if the landing gear shock strut appears to be "deflated" or if the pilot indicates to the ground crew that he detected an abnormal "spongy" landing that could be due to improper strut fluid level. Slow hydraulic fluid leakage may go undetected because commercial aircraft are not typically monitored by a single user. When line mechanics note that landing gear struts are "low" they typically add nitrogen gas to "inflate" them to the proper extension. However, replacing the hydraulic fluid with nitrogen results in a gear that will not absorb enough energy and may fail. Verification of hydraulic fluid level requires a multi-point gear extension measurement routine in which the strut is emptied and refilled with a known volume of hydraulic fluid. This requires the airline to take the aircraft out of service for an extended time in order to perform maintenance. Maintenance typically requires full quality assurance surveillance and generation of paperwork records to re-certify the aircraft for further use.

The problem of having no way to measure hydraulic fluid level has surfaced at numerous meetings of the Aerospace Landing Gear Systems Committee of the Society for Automotive Engineers (SAE). No practical solution for determining strut hydraulic fluid level is currently known to be used to meet this need.

The solution of installing fluid level sight glasses has been suggested, but has not been received favorably by the aircraft industry or implemented except in laboratory studies. However, sight glasses require hardware modification, may weaken the strut, may increase potential for leakage and may make the strut hardware more fragile since most sight glass window materials such as glass could be subjected to breakage. Additional weight associated with incorporating sight glasses on aircraft is another drawback.

Another concept is inserting devices inside the strut such as floats or floating magnets. However, adding invasive devices inside the strut increases hardware complexity and introduces potential for breakage or failure of the sensing devices, possibly resulting in loose parts inside the strut. Installation and repair may require hardware design modifications to provide means of gaining access to the inside of the strut.

Ultrasonics has been used for many applications¹⁻⁵. This paper presents an ultrasonic technique⁶ to nonintrusively measure hydraulic fluid level in a strut in the field by making measurements from the exterior surface of the strut's side-wall quickly and easily using a removable hand-held transducer.

ULTRASONIC TECHNIQUES

The ultrasonic techniques presented here use the principle that when ultrasonic waves reach an interface at which the acoustic impedance suddenly changes, some of the signal passes through and some is reflected back. The greater the impedance mismatch, the more signal is reflected back. The smaller the mismatch, the less signal is reflected and the more passes through. In the techniques presented here, when acoustic waves propagating through metal reach a metal-gas interface

with a gas such as air or nitrogen, most of the signal reflects back and almost none propagates into the gas. When acoustic waves propagating through metal reach a metal-liquid interface with liquid such as hydraulic fluid, much of the signal propagates through into the liquid and a fractional amount reflects back. The acoustic waves that propagate through the hydraulic fluid reflect off internal structures and return back to the transducer.

PULSE-ECHO TECHNIQUE

The pulse-echo technique uses a removable hand-held ultrasonic transducer to inject ultrasound into the desired side-wall area of the strut fluid chamber and determine the presence of a reflected sound wave. The reflected sound wave would be one that is reflected off of either a central structure (such as a metering pin or tube), or the opposite interior wall of the strut. Because the sound waves will not pass through the gas, they would therefore not be seen unless there is hydraulic fluid behind the location of the ultrasound transducer. Thus, the location on the strut at which one finds the reflected signal appearing and disappearing as the transducer is moved is the location of the fluid level inside the strut.

The pulse-echo method uses an ultrasonic transducer as illustrated in figures 2 and 3 to send and receive ultrasonic signals in a pulse-echo configuration to detect the ultrasonic waves reflected from interfaces within the interior of the strut. The transducer is acoustically coupled to the outside surface of the strut using liquid couplant. An ultrasonic system produces electronic signals which go out to drive the transducer. The transducer converts the electronic signals to ultrasonic waves which propagate through the strut. When these ultrasonic waves reflect from interfaces and return to the transducer, the transducer generates electronic signals that go back into the ultrasonic system and are typically displayed using an oscilloscope or other display means or indicator.

In figure 2, ultrasonic signals passing through the strut wall, encounter gas inside the strut, and do not pass into the gas, therefore echo signals are not received back to the transducer at the delay time. In figure 3, the ultrasonic signal passing through the strut wall, encounter hydraulic fluid instead of gas, and the ultrasonic signals pass into the hydraulic fluid. The signals propagate through the hydraulic fluid, and reflect from the nearest internal interface which in this example is the opposite internal wall of the strut, and propagate back to the transducer. Arrival of the received echo signal at the transducer is delayed as shown by the oscilloscope in figure 3 because the hydraulic fluid provides a long path length for propagation of the ultrasonic signal. Figure 4 illustrates an ultrasonic transducer being used to measure fluid level in a typical aircraft hydraulic strut.

To locate the hydraulic fluid level, the transducer is scanned (ultrasonically coupled to the outer surface of the strut at different locations) in a direction

perpendicular to the plane of the liquid-gas interface until the delayed echo signal appears and disappears. The position on the hydraulic strut where the echo signal can be made to appear and disappear at the anticipated time delay by scanning the transducer back and forth over a short distance is the hydraulic fluid level. Delay time can be predetermined and depends on strut geometry and material as well as the type of hydraulic fluid. The operator must distinguish between the signal traveling one round trip through the hydraulic fluid and the signal reverberating back and forth in the strut wall. Accuracy of this pulse-echo technique depends on parameters such as diameter of transducer and signal threshold levels chosen.

Field Demonstration of Pulse-Echo Technique

The pulse-echo technique was successfully demonstrated on an A-6 aircraft strut on the carriage at the Aircraft Landing Dynamics Research Facility (ALDF) at NASA LaRC. The strut was specially-equipped with a sight glass to show actual hydraulic fluid level for laboratory studies. Figure 5 shows photographs of the landing gear with sight glass and a cutaway depiction of the hydraulic fluid level in the strut.

The measurements were performed with commercial off-the-shelf equipment. A Harisonic model MC0208 magnetic 2.25 MHz fingertip ultrasonic transducer was used. The ultrasonic system used was a Panametrics model 5072PR pulser-receiver. A 200 MHz Tektronix model 2445B analog oscilloscope was used to display the ultrasonic signals.

The ultrasonic system was set up and the delay time of the ultrasonic signal with hydraulic fluid present was determined for the A-6 strut. Figure 6 shows the transducer being held on the strut and scanned while observing the oscilloscope. Figure 7 shows the ultrasonic signals displayed on the oscilloscope. The ultrasonic technique identified the same fluid level in the strut as that shown by the sight glass. Accuracy of this technique will depend on factors such as transducer diameter and threshold level used. The transducer used had a piezoelectric element 1.27 cm in diameter. For these tests, accuracy was approximately +/- 0.32 cm.

Blind Test of Pulse-Echo Technique

A blind test was then performed as follows. The sight glass shown in figure 5 was covered from view, then fluid level was changed. An individual who did not know the new fluid level was instructed how to do the pulse-echo measurement and performed the fluid level measurement using the subject technique. After determining fluid level with the ultrasonic technique, the actual level at the sight glass was revealed and agreed with that measured with the ultrasonic technique. This blind test also indicated that it was a simple matter to instruct an individual to use the technique and obtain good results.

REVERBERATION TECHNIQUE

Another way to measure hydraulic fluid level is by using ultrasonic signals that reverberate back and forth in the strut wall as shown in figures 8 and 9. This reverberation technique uses the same equipment as was used for the pulse-echo technique. However, the reverberation technique does not require ultrasonic echo signals to pass through the hydraulic fluid and reflect back from an interface inside the strut. This makes the reverberation technique ideal for struts where the internal interfaces cannot produce ultrasonic reflections received back that are strong enough to be detected by the ultrasonic transducer and measurement system. For example, a strut containing a metering tube equipped with holes may not reflect ultrasonic waves well enough if the waves impinge where a hole is.

The reverberation technique takes advantage of the principle that the amplitude of an ultrasonic signal that is bouncing back and forth in the strut wall will decay with each round trip or reverberation through the wall. The shape of the echo pattern seen on an oscilloscope will be different depending whether gas or hydraulic fluid is present inside the strut at that location. If gas is present as in figure 8, less energy is lost with each reverberation because the reflection coefficient is high and most of the ultrasonic signal reflects back into the strut wall. This results in an echo pattern that decays slowly. If hydraulic fluid is present instead of gas as shown in figure 9, more energy is lost with each reverberation because the reflection coefficient is smaller allowing more ultrasonic energy to leave the strut wall and be lost by passing into the hydraulic fluid. This results in an echo pattern that decays faster. Strut hydraulic fluid level is the location at which the reverberation decay rate of the echo pattern is seen to change by scanning the transducer back and forth a short distance in the direction perpendicular to the plane of the liquid-gas interface.

When the pulse-echo technique was demonstrated on the A-6 strut as shown in figure 7, this test also demonstrated the reverberation technique. The oscilloscope traces from figure 7 are presented again in figure 10 with emphasis placed on the echo pattern. The long echo pattern in the top oscilloscope trace in figure 10 occurs because gas is present inside the strut and this causes the ultrasonic waves to decay more slowly than the echo pattern in the bottom oscilloscope trace in figure 10 where hydraulic fluid is present. Had the pulse-echo technique not worked in this example, the reverberation technique could have been used to detect hydraulic fluid level instead. Accuracy of the reverberation technique is similar to that for the pulse-echo technique.

CONCLUSION

This is a technique for nondestructively determining hydraulic fluid level in aircraft struts quickly and easily from the outside of the strut. The technique does not

require modifying the strut, adding sight glasses or placing sensors inside the strut. The technique eliminates the need to remove aircraft from service to perform maintenance or extensive test procedures to assess fluid level. The technique does not require machining a flat surface on the strut, so that makes it transparent to gear manufacturer and easy for a technician to implement. The simplicity and ease of use of this technique also makes it feasible/practical to perform periodic inspection to assure continued integrity of struts. Commonly, the service condition of a landing gear strut is unknown at the aircraft's destination, so the technique disclosed herein makes it feasible to periodically check this condition nondestructively, quickly, and without removing the aircraft from service. The ultrasonic techniques presented in this paper can also be used to measure liquid level in various types of containers other than aircraft hydraulic struts.

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CONTACT

Sidney G. Allison received his BS in Engineering Mechanics in 1971 from Virginia Polytechnic Institute and State University, Blacksburg, Virginia. In 1979 he joined NASA Langley Research Center and is currently a Research Engineer in the Nondestructive Evaluation Sciences Branch. He holds 5 US patents, has co-authored over 20 publications and received 20 NASA

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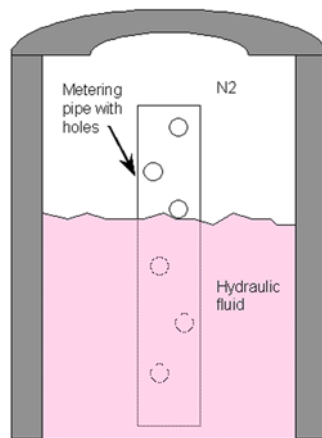


Figure 1. Typical aircraft hydraulic strut configuration with nitrogen gas above the hydraulic fluid. Struts for some aircraft such as the A-6 contain a metering pipe in the middle with holes as shown above. The challenge is to measure hydraulic fluid level quickly and easily from outside the strut without intrusion or hardware modification.

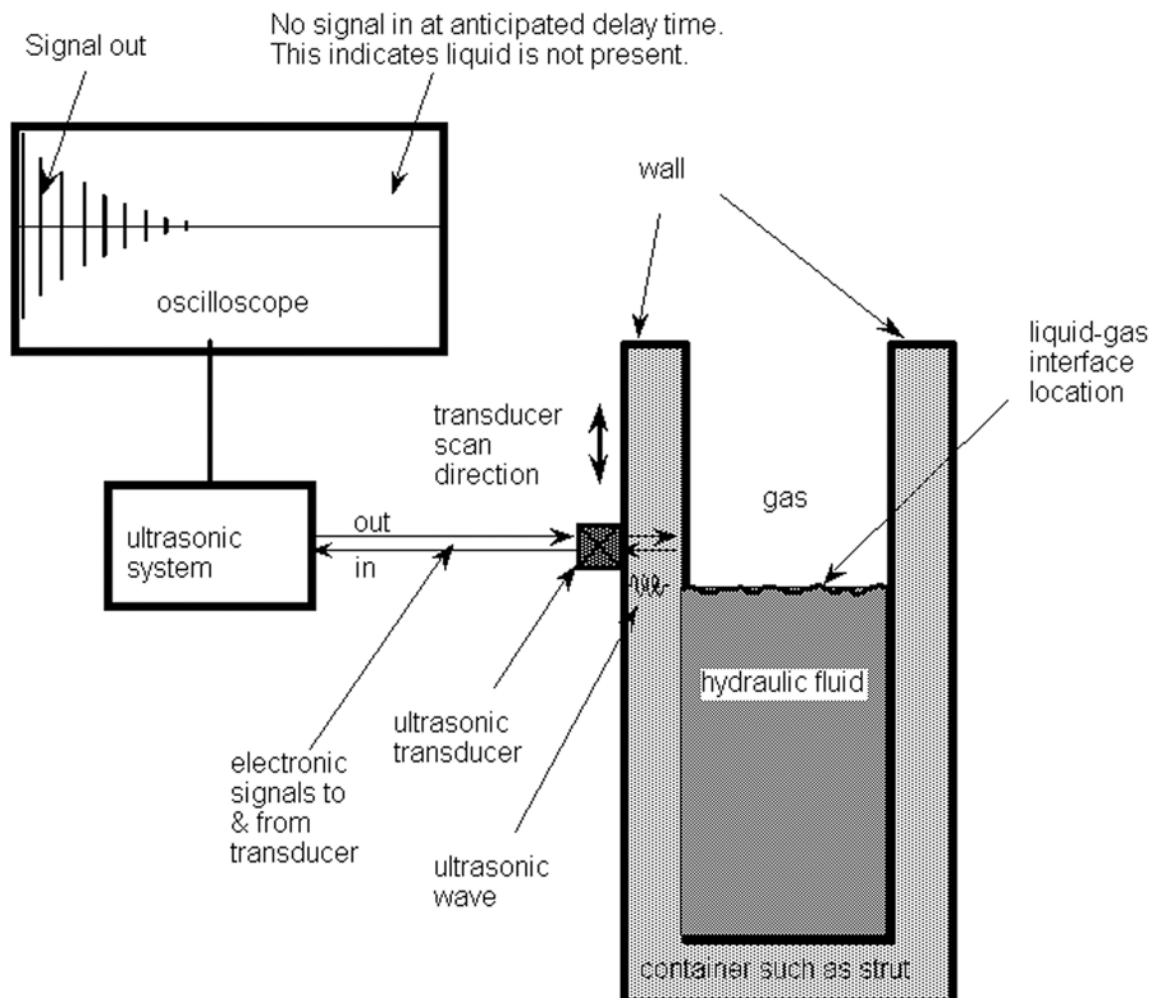


Figure 2. The ultrasonic technique uses one transducer in a pulse-echo configuration. When the pulse-echo technique is applied at a location where gas is present instead of hydraulic fluid as shown above, it does not generate the echo signal expected to be received at the anticipated delay time.

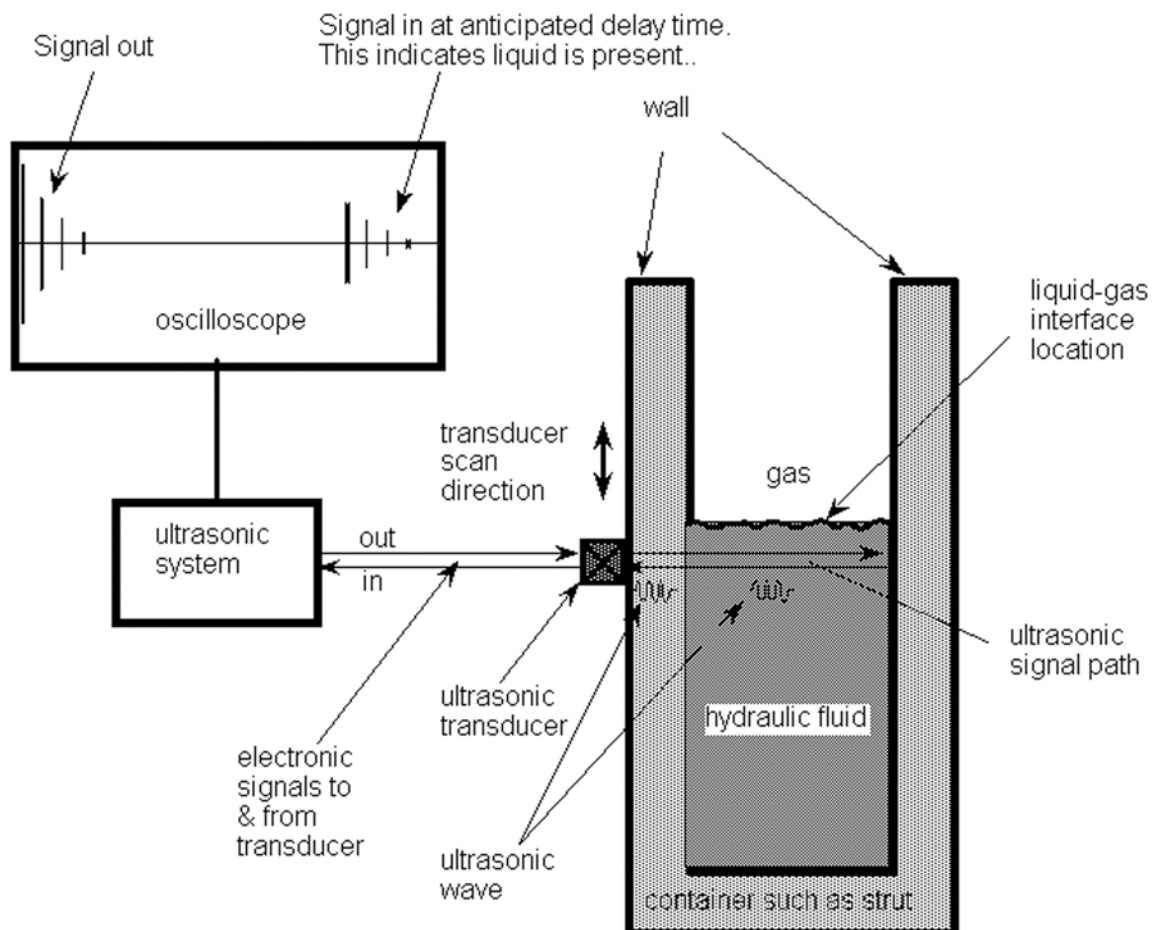


Figure 3. When the ultrasonic pulse-echo method is applied at a location with hydraulic fluid present, it does generate the echo signal received at the anticipated delay time. Hydraulic fluid level is the location at which the echo can be made to appear and disappear by scanning the transducer a short distance in a direction perpendicular to the plane of the liquid-gas interface.

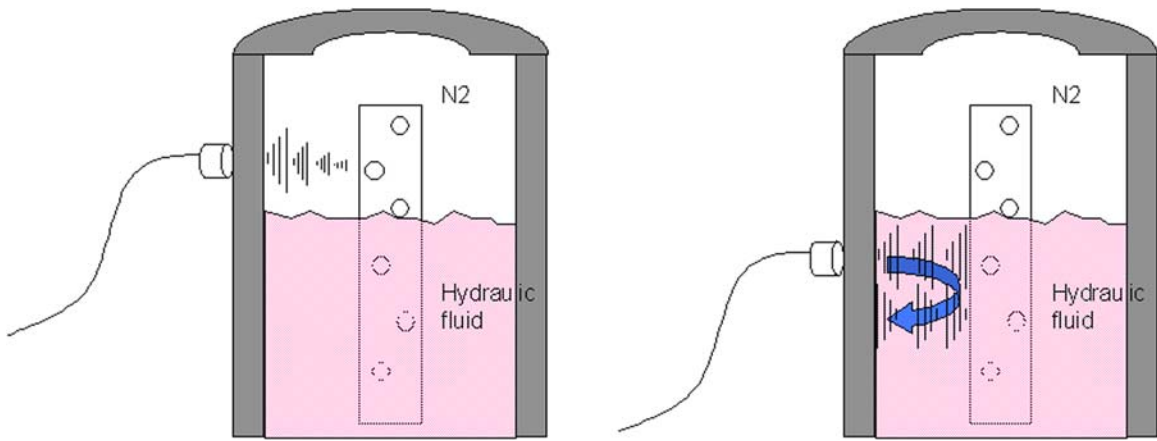


Figure 4. Ultrasonic pulse-echo method applied to typical strut configuration. Ultrasonic signals do not pass through nitrogen gas, but do pass through hydraulic fluid, reflect from internal structure and return back to the transducer.

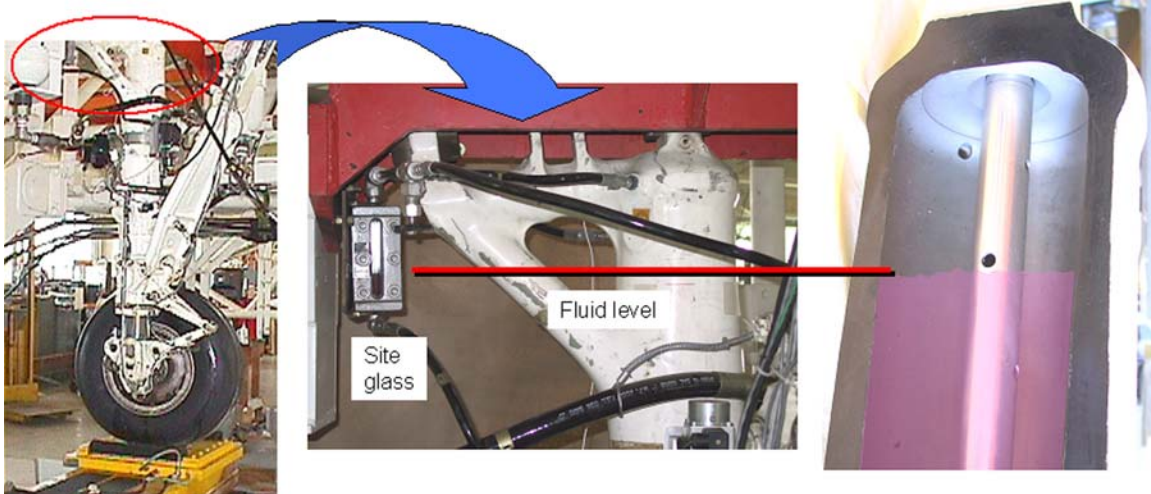


Figure 5. Tests were conducted at the Aircraft Landing Dynamics Facility (ALDF) shop at NASA Langley using an actual A-6 attack aircraft main gear. This gear already had a site glass installed to allow the upper chamber hydraulic fluid level to be visualized for another program. This was a perfect test bed for this technology.

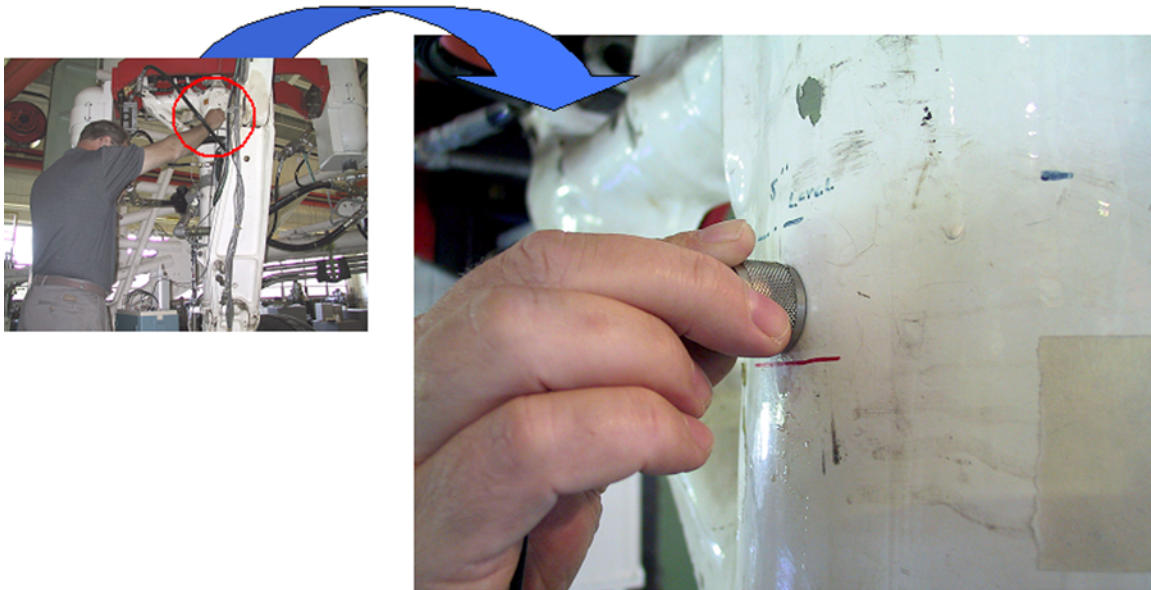


Figure 6. Ultrasonic transducer is acoustically coupled to the A-6 strut using liquid couplant. Machining a flat surface on the strut was not necessary.

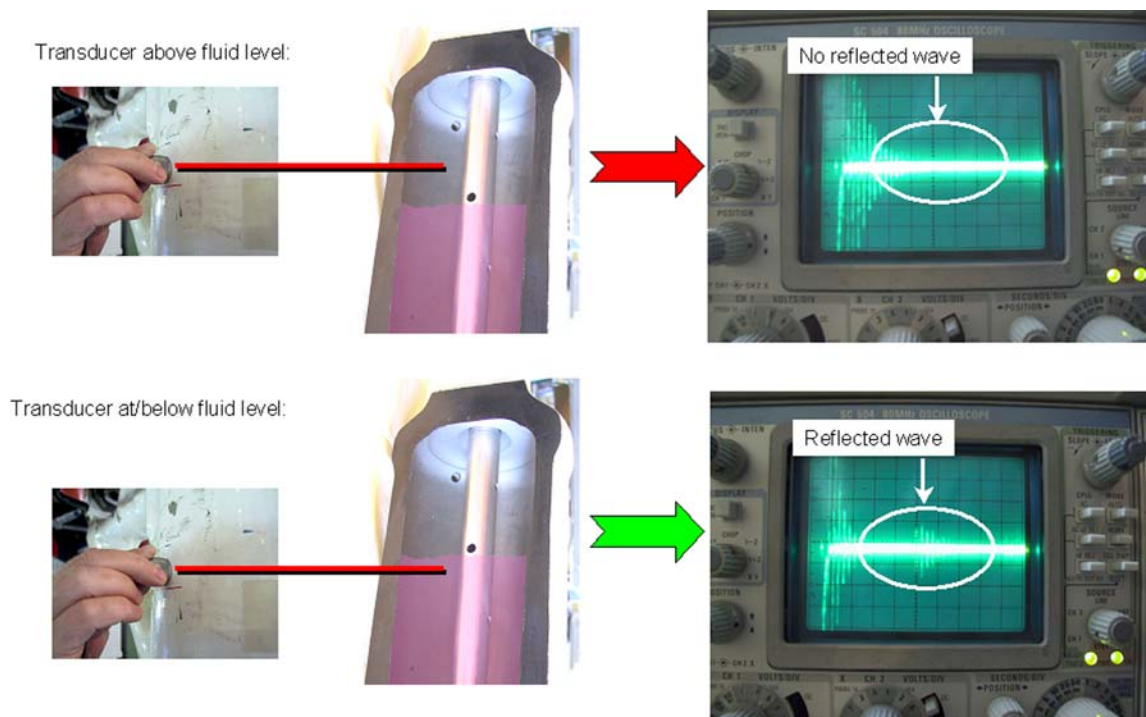


Figure 7. Ultrasonic signals from the pulse-echo testing on the A-6 strut are seen in the oscilloscope traces. The top trace indicates gas is present and the bottom trace indicates hydraulic fluid is present. Hydraulic fluid level is determined by scanning the transducer until the reflected wave appears and disappears. The signal out in the top trace shows many round trip reverberations within the strut wall because gas is present inside the strut and does not absorb much acoustic energy. The bottom trace contains fewer reverberations because hydraulic fluid is present and absorbs more energy than the gas absorbs. Reverberation will be discussed later in this paper.

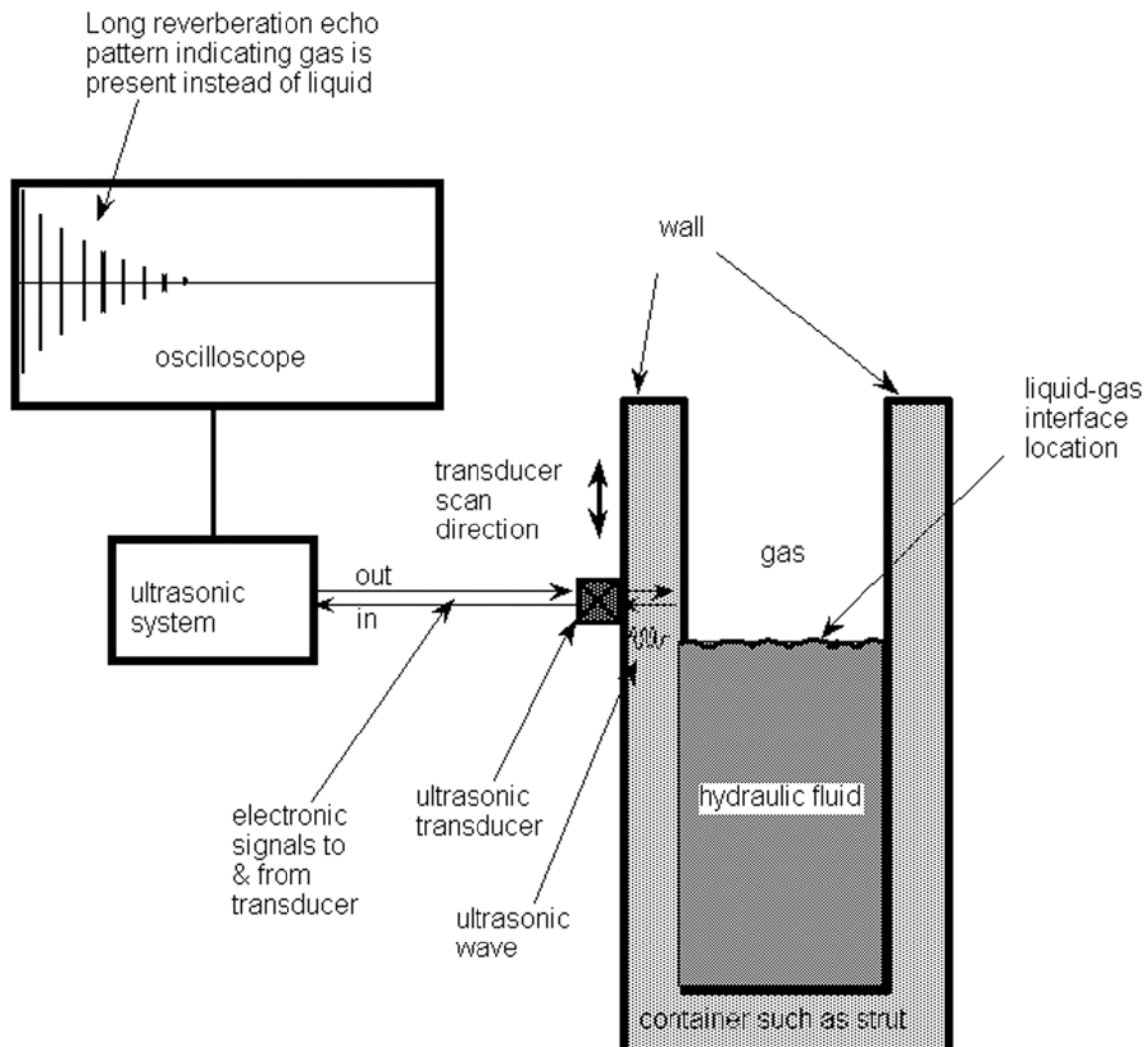


Figure 8. The reverberation technique is another way to measure hydraulic fluid level using the same measurement equipment. If gas is present as shown in this figure, a long reverberation pattern is seen on the oscilloscope.

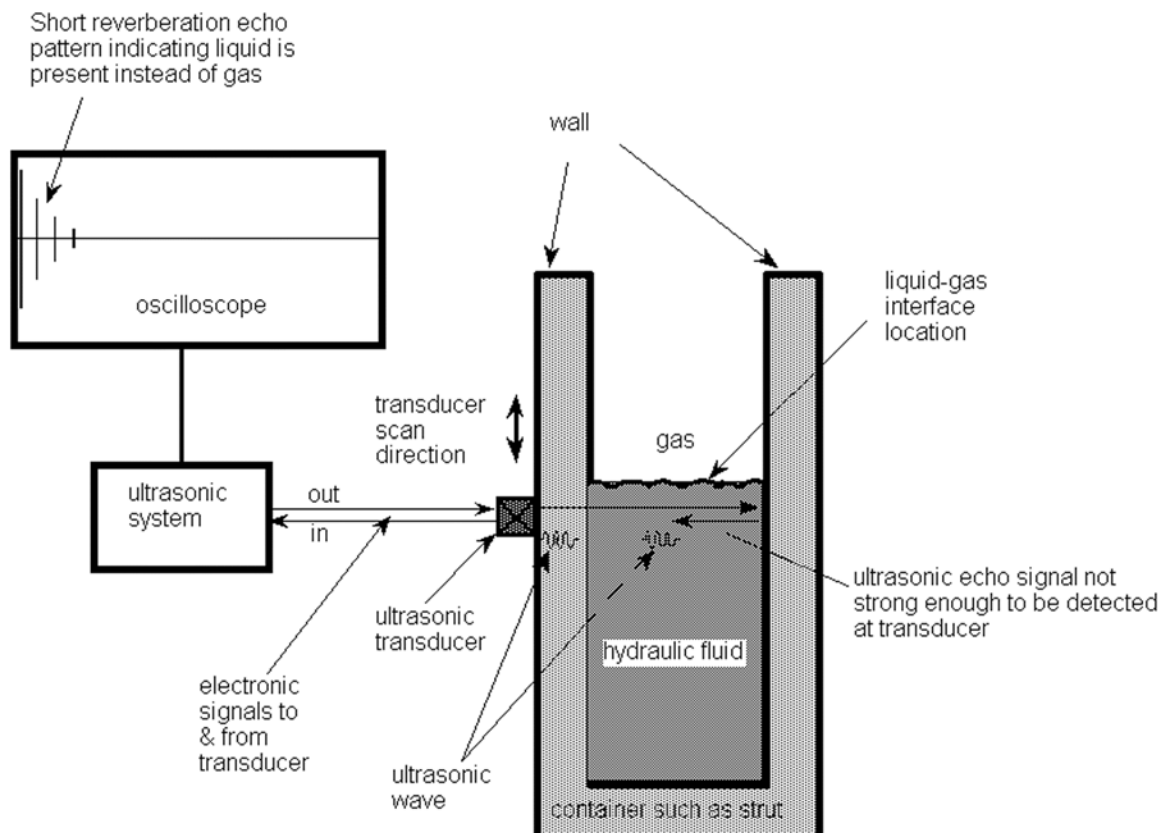


Figure 9. When the transducer is placed where hydraulic fluid is present, a short reverberation pattern is seen on the oscilloscope. Hydraulic fluid level is measured by scanning the transducer until the reverberation echo pattern changes back and forth from long to short.

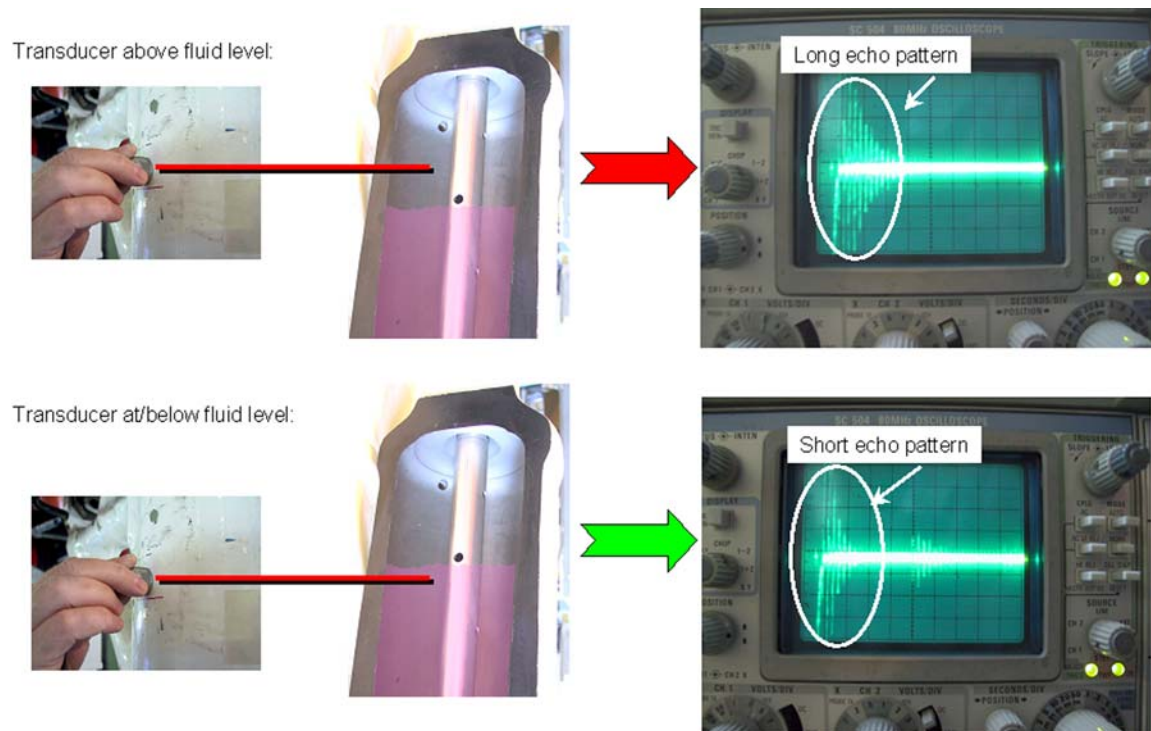


Figure 10. Reverberation technique provides an alternate means of measuring hydraulic fluid level on the A-6 aircraft strut. If the pulse echo technique had not worked on this strut, the reverberation technique could have been used instead.